

Heat Recovery Systems

API RECOMMENDED PRACTICE 669
FIRST EDITION, JUNE 2022



American
Petroleum
Institute

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees makes any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be used. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this recommended practice should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required to conform to the standard.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 Scope	1
2 Normative References	1
3 Terms, Definitions, Acronyms, and Abbreviations	1
3.1 Definitions	1
3.2 Acronyms and Abbreviations	3
4 General Information	3
4.1 Utility Systems	3
4.2 Mechanical Descriptions	3
4.3 Specific Heat Recovery Applications	4
Annex A (informative) Steam Systems	5
Annex B (informative) Hot Oil and Other Heat Transfer Fluids	12
Annex C (informative) Hot Water/Glycol Systems	17
Annex D (informative) Watertube WHRU Configurations	20
Annex E (informative) Firetube WHRU Configurations	23
Annex F (informative) FCCU/RCCU Process Units Heat Recovery Systems	48
Annex G (informative) Process Heater Convection Sections	50
Annex H (informative) Gas Turbine Exhaust Heat Recovery Systems	51
Annex I (informative) Thermal Oxidizers Heat Recovery Systems	52
Annex J (informative) Process/Flue Gas Heat Recovery Systems	56
Annex K (informative) Process Liquid Heat Recovery Systems	60
Annex L (informative) Sulfur Recovery Unit Heat Recovery Systems	61
Annex M (informative) Heat Flux and Circulation Ratio	68
Bibliography	73

Figures

A.1 Typical Steam System Components as Part of a Watertube Steam Generator	7
B.1 Typical Molten Salt System	13
B.2 Typical Heat Transfer Fluid System with Waste Heat Recovery Unit	14
D.1 Typical Natural Circulation Watertube	21
D.2 Typical Forced Circulation System	22

Contents

	Page
E.1 Typical Horizontal Firetube with External Drum HRSG	26
E.2 Typical Vertical Firetube with External Drum HRSG	26
E.3 Typical Firetube Kettle Type HRSG	27
E.4 Typical Insulated Metal Ferrule	28
E.5 Typical Straight Ceramic Ferrule	29
E.6 Typical Headed Ceramic Ferrule	30
E.7 Tube Arrangements with Straight, Hex-head, and Square-head Ferrules	31
E.8 Typical Damage when Ferrule Fit is Too Tight	32
E.9 Conventional Strength Welds	33
E.10 Full Depth Strength Weld	33
E.11 Back Face (Shell Side) Weld	34
E.12 Typical Channel to Tubesheet-shell Interconnections	36
E.13 Typical Knuckles for Full Diameter Kettles	37
E.14 Typical Dual-compartment Firetube HRSG	39
E.15 Typical Two-pass, Separate Shells, Firetube HRSG	40
E.16 Typical Two Tube Pass Firetube HRSG	42
E.17 Typical Internal Bypass System with Valve and Damper	43
M.1 Example of Circulation Ratio Variability with Steam Rate	71

Tables

C.1 Freezing Points of Ethylene Glycol Based Water Solutions	19
C.2 Freezing Points of Propylene Glycol Based Water Solutions	19
M.1 HRSG Firetube and Watertube Local Heat Flux	69

Introduction

Users of this recommended practice (RP) need to be aware that further or differing requirements can be needed for individual applications. This RP is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the vendor should identify any variations from this RP and provide details.

This RP requires the purchaser to specify certain details and features.

In this RP, System International (SI) units are used and where practical, U.S. customary (USC) units are included in parentheses for information.

Heat Recovery Systems

1 Scope

1.1 This recommended practice (RP) provides guidelines for heat transfer equipment used in waste heat recovery systems in the petroleum, petrochemical, and natural gas industries. Details of related equipment designs are included only where these are necessary to ensure proper design and operation and safe interaction with the heat recovery system. It indicates areas that need attention and offers information and descriptions of various types of heat transfer equipment available to aid in the selection of the appropriate heat recovery system.

1.2 This RP does not include detailed requirements for:

- process to process heat recovery systems,
- gas turbine exhaust heat recovery,
- CO boilers, or
- convection sections used within fired heaters.

1.3 The waste heat recovery systems included in this RP are typical of those currently in use and should not limit the use of alternate systems.

1.4 Instrumentation and controls for waste heat recovery systems are sometimes mentioned but is not meant to completely define all requirements. Other standards and documents, such as API Recommended Practice 556, *Instrumentation, Control, and Protective Systems for Fired Heaters*, should be used to fully define the needed instruments and controls.

2 Normative References

There are no normative references in this document.

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

approach temperature

The difference between the saturation temperature of the steam at the selected pressure and the temperature of the water leaving the economizer.

3.1.2

desuperheater attenuator

A device located internal or external to the HRSG that controls the exit temperature of the steam from the superheater. The device typically injects water with very low solids content into the steam to control the steam temperature by reducing it. Also called an attenuator.

3.1.3

downcomer

A heated or unheated pipe carrying water from the steam drum to an evaporator/generator section of an HRSG.

3.1.4 evaporator generator

The portion of the HRSG in which water is boiling to form steam. Typically, a mixture of water and steam exists at the exit of this portion. In some configurations, the steam and water are separated prior to leaving this portion of the HRSG. Also referred to as a steam generator section.

3.1.5 economizer

The portion of the HRSG where incoming feedwater temperature is raised to less than saturation temperature by recovery of the heat from the heating medium.

3.1.6 ferrule

A high temperature resistant metallic or ceramic shaped tube insert provided at the tube and tubesheet area to insulate components from high temperatures and to limit heat transfer.

3.1.7 firetube HRSG

A shell-and-tube heat exchanger in which steam is generated on the shell side by heat transferred from hot fluid flowing through the tubes.

3.1.8 heat recovery steam generator (HRSG)

A system in which steam is generated and may be superheated or water heated by the transfer from heat medium usually gaseous products of combustion or other hot process fluids.

3.1.9 heat recovery system

A system that transfers energy from one medium to a second medium for reuse.

3.1.10 pinch temperature

The difference between the heating medium temperature leaving the steam generator section and the steam's saturation temperature at the selected pressure.

3.1.11 process fluid

The heating medium used to supply the heat to the utility fluid.

3.1.12 riser

A heated or unheated pipe carrying water and steam from an evaporator/generator section of an HRSG to the steam drum.

3.1.13 shell-and-tube watertube HRSG

A shell-and-tube heat exchanger in which steam is generated in the tubes by heat transferred from a hot fluid on the shell side.

3.1.14 steam drum

A pressure vessel whose primary purpose is to separate water and steam.

3.1.15 superheater

The portion of the HRSG in which saturated steam is heated to higher temperatures.

3.1.16

waste heat recovery unit (WHRU)

A non-fired heat exchanger in which waste heat is transferred to a cold fluid which is not water being generated to steam.

3.1.17

watertube

A multiple tube circuit heat exchanger in which the utility fluid flows inside the tubes and the heating medium flows over the tubes. Most commonly the tube contains water in a water/steam system.

3.1.18

watertube low-pressure casing HRSG

A multiple tube circuit heat exchanger within a gas-containing casing in which steam is generated inside the tubes by heat transferred from a hot gas flowing over the tubes.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

BFW	boiler feedwater
CR	circulation ratio
FAC	flow accelerated corrosion
FCCU	fluid catalytic cracking unit
HRSG	heat recovery steam generator
HTF	heat transfer fluid
MAWP	maximum allowable working pressure
NPSH	net positive suction head
RCCU	residual catalytic cracking unit
SRU	sulfur recovery unit
TO	thermal oxidizer
TRSG	thermal reactor steam generator
WHB	waste heat boiler
WHRU	waste heat recovery unit

4 General Information

4.1 Utility Systems

4.1.1 See Annex A for information on “Steam Systems”.

4.1.2 See Annex B for information on “Hot Oil and Other Heat Transfer Fluid Systems”.

4.1.3 See Annex C for information on “Hot Water/Glycol Systems”.

4.2 Mechanical Descriptions

4.2.1 See Annex D for information on “Watertube WHRU Configurations”.

4.2.2 See Annex E for information on “Firetube WHRU Configurations”.

4.3 Specific Heat Recovery Applications

4.3.1 See Annex F for information on “FCCU/RCCU Process Unit Heat Recovery Systems”.

4.3.2 See Annex G for information on “Process Heater Convection Sections”.

4.3.3 See Annex H for information on “Gas Turbine Exhaust Heat Recovery Systems”.

4.3.4 See Annex I for information on “Thermal Oxidizers Heat Recovery Systems”.

4.3.5 See Annex J for information on “Process/Flue Gas Heat Recovery Systems”.

4.3.6 See Annex K for information on “Process Liquid Heat Recovery Systems”.

4.3.7 See Annex L for information on “Sulfur Recovery Unit Heat Recovery Systems”.

4.3.8 See Annex M for information on “Heat Flux and Circulation Ratio”.

Annex A

(informative)

Steam Systems

A.1 General

A.1.1 Steam systems are used for recovering waste energy from a process or flue gas stream and returning that energy by vaporizing water to steam for low, medium, or high-pressure steam systems within the plant. There are also opportunities for preheating BFW as well as superheating steam if the configuration benefits.

A.1.2 Steam systems may be closed, in which the condensate leaving the steam consumers is recovered and returned to boiler/steam generator, or they may be once through systems, in which the steam produced is often used in direct contact with the process medium and is non-recoverable.

A.1.3 There are many applications for steam generating systems including sulfur recovery units (sulfur condensers and thermal reactor steam generators), gas turbine exhaust systems, incinerator waste heat exchangers, process steam generators.

A.2 Boiler Feed Water/Condensate

A.2.1 Water conservation and quality control are important for closed systems and the boiler feedwater (BFW)/condensate is ideally clean water with minimal contaminant. Typically, de-aeration and chemical dosing are applied to the makeup water. Blowdown from the boiler drum(s) is used to maintain the quality of the boiler feedwater and prevent the buildup of impurities. The relatively high cost associated with the supply and treatment of makeup water means that it is important to minimize losses from the system and recirculate condensate wherever possible.

A.2.2 The steam exiting the HRSG should be of specified purity (contaminants) and quality (water content). Failure to control the steam purity is likely to accelerate damage to downstream equipment. For steam that is used in direct contact applications and is not recovered, the water quality and dryness of the steam may be less stringent but must still be adequate to prevent scaling and damage to the boiler/steam generator and downstream equipment. Contaminants can be controlled as with any steam generating or boiler system. Refer to API Recommended Practice 538 for additional detail on feedwater preparation, chemical treatment, and steam purity.

A.2.3 In most closed system applications, it is preferable for the quality of the steam (the dryness) to be high. Water droplets entrained within the steam can have a detrimental impact on the downstream equipment, possibly causing fouling or scaling. Water droplets carried along at high speed in steam piping systems can cause erosion of pipes, fittings and valves and can cause considerable damage if allowed to impact steam turbine blades. If there is a large amount of water carried over into the steam mains/headers and insufficient means of removing it, pooling could occur within these lines which may result in water hammer or slugging.

A.2.4 To achieve a high steam quality at its source, demister pads or other types of steam/water separation devices may be installed at the outlet of the steam generator, or these may be used internal or external to a steam drum. As the steam flows through the distribution mains/headers, some cooling and condensing will occur (unless superheated) and the quality will be reduced. Steam separators and steam traps may be installed within the mains/headers to ensure that the steam quality reaching the consumers remains high. Refer to API Recommended Practice 538 for additional details on steam purity.

A.2.5 Superheating can be used to ensure the dryness of the exported steam. A high steam quality into the superheater section is desirable to avoid fouling of the superheater heat transfer surface. Reducing the steam pressure can be another means of increasing the dryness of the steam depending upon where the steam system

operating conditions are on the Mollier diagram; e.g. reducing the pressure of high-pressure saturated steam to around 4000 kPa(a) (580 psia) or higher will reduce the steam quality. In once through applications low quality steam may be acceptable and the measures described above may be unnecessary but the potential issues of erosion and condensate buildup in the distribution lines must still be addressed.

A.3 Steam System Components

A.3.1 Typical Steam System Components

Figure A.1 shows a sketch of typical steam system components. Not all components are used in every design nor are all the needed components shown.

A.3.2 Steam Drum

A.3.2.1 The steam drum provides several functions within the steam system. Primarily it provides phase separation for the steam/boiler water stream returning from the evaporator but also serves to provide adequate boiler water holdup to ensure constant flow to the evaporator. A drum will typically be provided with level control and safeguarding to ensure that the makeup boiler water flow is balanced with the steam export rate, blowdown rate, and the liquid level within the drum remains between safe limits for operation. Maintaining the vapor space above the liquid level is also important for achieving the required steam quality leaving the steam drum.

A.3.2.2 The boiler water quality within the drum should be routinely monitored below the liquid level through sampling. Blowdown lines (continuous and/or intermittent) are employed to control the buildup of dissolved solids. The rate of continuous blowdown or frequency of intermittent blowdown will depend on the quality of the makeup boiler water.

A.3.2.3 In a natural circulation system, the drum must always be mounted above the evaporator. In a forced circulation system, the drum is typically above the evaporator but can be below the evaporator when the system is properly designed. In all cases it must be elevated above the boiler water circulation pumps to prevent cavitation at the pump inlet by ensuring sufficient net positive suction head (NPSH). Designing to ensure that all heat transfer surfaces are filled/covered with water even if the pumps stop makes the system intrinsically safe. This may mean stopping the heating medium flow into the system.

A.3.3 Liquid-vapor Separation Devices

The sizing of the vapor space above the liquid level of the steam drum will determine the amount of water entrainment within the export steam – some entrainment is inevitable. Where the process demand is for very dry steam it will be necessary to install separation devices to minimize liquid entrainment. The type and size of the separation device can be tailored to achieve a specific steam quality for the given export flow. Separation equipment will create pressure drop and this could be significant when selecting the separation device.

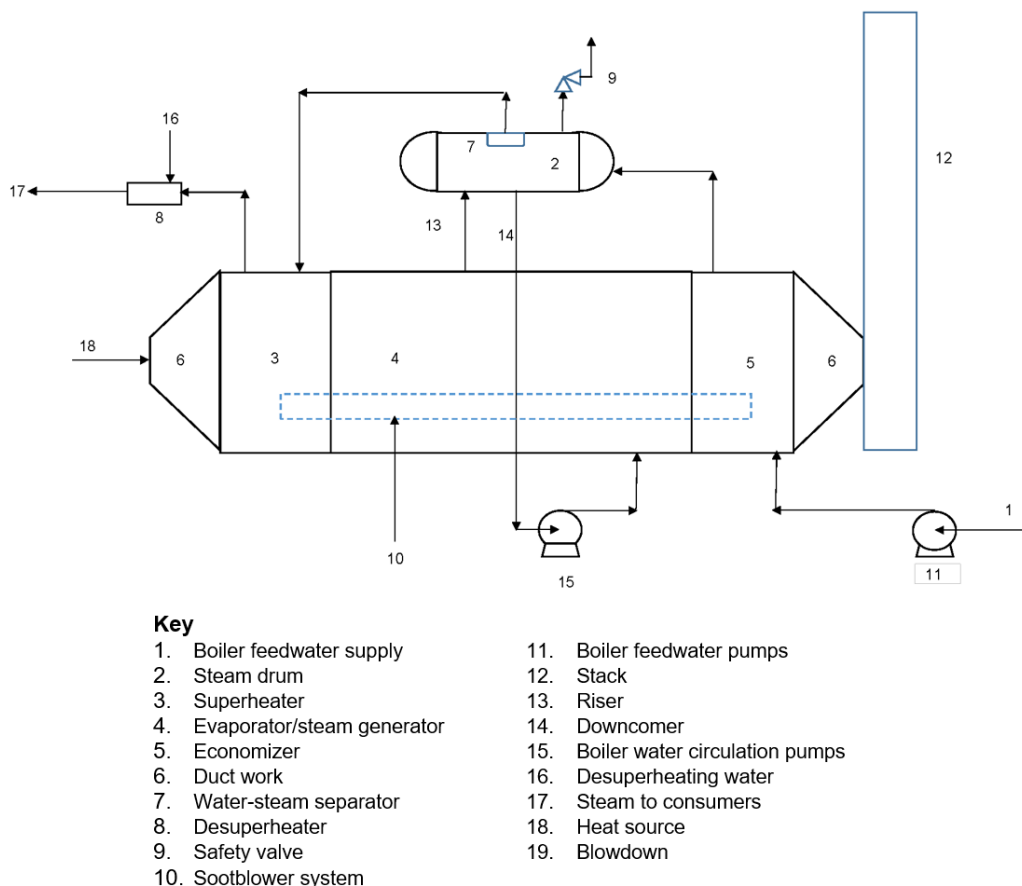


Figure A.1—Typical Steam System Components as Part of a Watertube Steam Generator

A.3.4 Downcomers

A.3.4.1 In a natural circulation system, the downcomers carry boiler water at the saturation temperature from the steam drum to the evaporator. The elevation of the steam drum provides the static head that drives the boiler water through the steam generation circuit. The number and size of downcomers must be determined according to the thermal and hydraulic requirements of the system.

A.3.4.2 In a forced circulation system, the downcomer will normally be a single line to the boiler water circulation pump(s). The static head gained by elevating the steam drum must exceed the required NPSH of the pump combined with the frictional losses in the downcomer to ensure vapor generation does not occur at the pump inlet.

A.3.5 Risers

The riser is the portion of the circuit which carries the steam/boiler water from the evaporator to the steam drum. A riser can be heated, or unheated, depending upon its contact with the heating medium.

A.3.6 Evaporator

A.3.6.1 The heat applied to the evaporator/steam generator causes the saturated boiler water to vaporize. In a natural circulation system water flow through the evaporator will normally be vertical. Sloped systems can also be used. The flow generated by the thermosiphon effect is a function of the amount of the heat recovered.

steam generated in the evaporator and the fluid hydraulics within the circuit. The total flow rate through the circuit relative to the flow rate of steam produced in the evaporator is known as the circulation ratio (CR). The designer must select the CR and heat flux so that phase separation does not occur within the evaporator which can lead to overheating and failure of the tubes. In a bank of evaporator tubes with a large reduction in heating medium temperature across the bank, consideration must be given to the variation in heat fluxes and steam generation rates within the various parts of the evaporator.

A.3.6.2 In forced circulation systems the evaporator tubes are more commonly horizontal. These circuits operate with higher velocities to stabilize the boiling and characteristically have fewer parallel heating paths and typically have multiple passes of each path through the heated zone. Where there is a change in elevation between inlet and outlet of the heating coils then the direction of flow should be upwards through the coil bundle. Since hydraulic system losses are overcome by the boiler water circulation pump the designer has greater flexibility in terms of circulation ratios and mass velocities. The designer should select a mass velocity high enough to ensure even flow distribution to each parallel pass.

A.3.7 Economizer and Superheater

A.3.7.1 Economizers are used to maximize heat recovery by preheating the BFW before it enters the steam drum. Economizers will be located at the back end of the heat recovery system usually at the point where there is no longer sufficient heat in the heating medium to generate steam. When using exhaust gas from a combustion source as the heating medium consideration must be given to the dew point of exhaust gases, particularly those containing sulfur species. Cold end corrosion is a common problem for low-temperature economizer surfaces. The BFW is usually co-current with the heating medium to keep the tube wall temperature above the acid gas dew point temperature. Depending on the layout there is more risk of damage due to flow instability or deposition occurring, therefore, economizers are normally not designed to vaporize any water.

A.3.7.2 The saturated steam leaving the steam drum, even very dry steam, can be cooled as it is transferred to the consumers causing condensation and the formation of water droplets to occur. This is undesirable in high velocity steam piping and mechanical consumers such as steam turbines where the impact of water droplets can cause erosion and damage. To prevent this saturated steam is often passed through a superheater and heated to a temperature above saturation that is sufficient to ensure the steam remains dry when it reaches the consumers. Superheating also increases the power that can be derived from the steam in steam driven equipment. In some systems, steam from external sources are added prior to entering the superheater.

A.3.7.3 The superheater is usually located in the hottest part of the heat recovery system, upstream of the evaporator. In some instances when the superheater may have to run-dry (i.e. no flow condition) and/or the inlet temperature of the heating medium is very high, some evaporator surface may be installed upstream of the superheater to provide some shielding. In this case, the heating medium temperature must be below the maximum allowable tube metal temperature.

A.3.8 Circulation Pump and Flow Regulation

A.3.8.1 In a forced circulation system, a pump is used to circulate the boiler water through the evaporator. The pump should be sized to provide sufficient flow to meet the required circulation ratio and generate sufficient head to overcome the pressure drop of the evaporator circuit. The NPSH required by the pump must not exceed the NPSH available. In critical service the pumps are often spared as loss of circulation flow will likely result in shut-down of the steam generation system.

A.3.8.2 The circulation flowrate will usually be controlled by either variable speed drive or a flow control device in the circulation line. Flow measurement and control should ensure that the design circulation ratio is achieved, and low-flow safeguards should cut off the heat input to the heating coils if the minimum safe circulation flowrate is not achieved.

A.3.9 Desuperheating

A.3.9.1 It is sometimes necessary, e.g. for turbines, to produce superheated steam to protect the equipment or provide temperature control. However, in thermal process applications it may be preferable to use steam closer to saturation temperature as this is usually more efficient for heat transfer and allows for lower heat exchange surfaces with lower design temperatures. Therefore, a proportion of the superheated steam produced may be de-superheated for use in such applications.

A.3.9.2 Desuperheating can be achieved by indirect heat exchange but more commonly it will be achieved by direct injection of water into the steam flow, either by means of a venturi or spray-type nozzle. The water should be high quality e.g. BFW or condensate. The impact of possible trace chemicals in injection water should be considered in these systems.

A.3.9.3 Desuperheating may also be used as a method of controlling the steam outlet temperature where there is no independent means of controlling the heat input into the superheater of the steam generator. It can reduce the dryness of the steam so intermediate desuperheating, located between banks of superheater surface, can be used to counter this.

A.3.10 Pressure Safety Valve (PSV)

Pressure safety valves (PSV) are an integral part of any steam system and are designed to prevent the system pressure from exceeding the MAWP of the system. A PSV is a spring-loaded device that is designed to open and vent steam from the system at a predetermined factory-set pressure. Typically, a steam system will have multiple PSVs.

NOTE Refer to API Standard 521 and other relevant jurisdictional codes for more information including sizing.

A.3.11 Steam Traps

Steam traps are used as a means of removing condensate and non-condensable gases from the steam distribution mains/headers to ensure the steam reaching the consumers remains dry and reduces the risk of water hammer developing within these lines. Steam traps allow the constant removal of condensate whilst preventing the escape of steam. The mechanism can either be mechanical, thermostatic, or thermodynamic. Properly installed float or thermostatic steam traps are also used to bleed air and other non-condensable gases from the steam system during start-up. They may also be used for the collection of condensate from steam consumers to route the condensate into the collection system. In some cases, they are used in lieu of condensate pots; in these cases, caution should be applied to eliminate water hammer.

A.3.12 Condensate Recovery

A.3.12.1 Condensate is produced when heat is released by condensing steam and then the condensate is collected by the use of either condensate pots or steam traps. The high cost of treating the water and the sensible heat remaining within the condensate means recovery of condensate for reuse is usually provided. Condensate will be collected in a receiver and then transported into the boiler feed vessel by pumping in a pressurized system. In the case of an atmospheric feed tank the pressure at the steam trap may be sufficient to return the condensate to the feed tank but some flashing at atmospheric pressure will occur and that steam produced will be lost from the system.

A.3.12.2 In plants with multiple steam consumers requiring different steam pressures the condensate from the high-pressure system may be flashed to produce medium or low-pressure steam that can be exported to the lower pressure steam mains/headers. Steam turbines also lower the steam pressure through operation, and this can be exported directly to the lower pressure steam main for further use after removing the condensate.

A.3.12.3 Care should be exercised when mixing water/condensate streams of different temperatures to avoid creating a water hammer.

A.3.13 Duct Work

Duct work may be provided between sections on the heating medium side to transport the heating medium. This ductwork design should provide uniform flow distribution of the heating medium, minimize heat loss to the atmosphere by using refractory linings or external insulation, and allowing for proper expansion of the ductwork in all directions often by utilizing expansion joints.

A.3.14 Trim, Instrumentation, and Controls

A well-designed system needs to provide trim connections to the fluids on both sides of the steam system to allow for installation of instrumentation and controls to monitor the operation of the system and to provide for operation and safety controls.

A.3.15 Online Cleaning/Sootblowing Systems

If the heating medium contains materials that can foul the heat transfer surfaces, an online cleaning system may be required. Sootblowers are typically used for this purpose, but other systems exist. The design of an online cleaning system needs to consider:

- the amount of fouling expected;
- the type of foulant that needs to be removed;
- the frequency of cleaning required;
- the impact of the cleaning medium, including on the heat transfer surface and supports.

Some other types of systems used include sonic horns, vibration (hammering), and water washing.

A.3.16 Pressure Design Codes

A.3.16.1 Steam systems are designed and fabricated in accordance with the Pressure Design Code. However, there may be jurisdictions where the use of a specific Boiler Code will be required in place of the Pressure Vessel Code. For example, ASME *BPVC Section VIII, Division 1* and ASME B31.3 or ASME *BPVC Section I* and ASME B31.1 could be required based on the jurisdiction's requirements.

A.3.16.2 Piping components in most configurations are designed and fabricated in accordance with the relevant Piping Code.

A.3.17 Blowdown Systems

This type of system includes valves, analyzers, and controls to regulate the boiler water chemistry.

A.4 Advantages and Disadvantages of Utility Steam

A.4.1 Advantages

Utility steam has the following advantages.

- a) Raw water is readily available and inexpensive compared with other heat transfer mediums.
- b) Steam is a nonflammable, nontoxic medium with low environmental impact (when used in closed systems).
- c) Steam carries a large amount of energy per unit mass.
- d) Transferring heat using latent heat is a very efficient process allowing for the reduction in size and capital cost of heat transfer equipment.
- e) Steam maintains a constant temperature as heat is transferred, resulting in even heat transfer.
- f) Versatility – A single steam generator installation can be used to derive steam at multiple pressure/temperature levels to suit a variety of consumers.
- g) Efficiency – With an economizer, a large proportion of the heat source available can be recovered and an efficient condensate recovery system can mean very little heat is wasted.

A.4.2 Disadvantages

Utility steam has the following disadvantages.

- a) A steam system has a relatively high capital cost compared with other systems. Depending on the source water quality, the system may need extensive water treatment facilities to improve the water quality to that needed for boiler feedwater.
- b) System design is complex and can result in operational issues if not performed correctly (e.g. inadequate condensate removal, water hammer, and equipment damage).
- c) Inspection and maintenance demands are more severe.
- d) Winterization concerns must be addressed for cold weather climates.
- e) Water may be scarce at some locations.
- f) Steam systems are corrosive and must be designed and treated properly.

Annex B

(informative)

Hot Oil and Other Heat Transfer Fluids

B.1 General

Hot oil and other liquid phase heat transfer fluid (HTF) systems are commonly used to provide heat to process fluid services as an alternative to steam heating systems or the use of direct fired process heaters. As compared to steam heated applications, a properly designed HTF system can provide for lower capital and operational costs due to lower operating pressures and the elimination of large diameter vapor piping, pressure control equipment and devices, condensate handling systems, and BFW treatment equipment and chemicals. Compared to direct fired heaters, HTF systems can provide more uniform heating to temperature sensitive process streams, eliminating local hot spots and providing improved accuracy of temperature control. It also allows for a single heating source (fired heater or heat recovery exchanger for the heat transfer fluid) to be located remotely from the process unit and allows for heat to be provided to multiple process services, at different temperature levels, as well as being able to provide both process heating and cooling needs.

B.2 Commercial Heat Transfer Fluids

B.2.1 General

There are many heat transfer fluids that are available as commercial products. These include a number of mineral oils as well as synthetic aromatic or silicone-based fluids. There is no single best HTF for all applications, and different fluids are designed for use for specific applications and technologies and for distinct temperature ranges from $-115\text{ }^{\circ}\text{C}$ to $+400\text{ }^{\circ}\text{C}$ ($-175\text{ }^{\circ}\text{F}$ to $+750\text{ }^{\circ}\text{F}$). Heat transfer fluids are designed with optimized properties to provide efficient heat transfer at their intended operating temperatures including high specific heat, density, and thermal conductivities while having low viscosity. They have low vapor pressures and high boiling ranges, which permit operation at low system pressures and at their maximum recommended operating temperatures.

B.2.2 Decomposition of Heat Transfer Fluids

All commercial HTFs are subject to time and temperature dependent decomposition. The HTF supplier provides maximum bulk fluid and film temperatures for the fluid which should be strictly observed. Decomposition of the fluid results in the formation of components which have both lower molecular weights and boiling points (low-boilers) and higher molecular weights and boiling points (high-boilers) than the original fluid. Low boilers can reduce the flash and fire point of the HTF and should be periodically vented from the system. High boilers are generally soluble in the bulk fluid to a certain degree, above which the fluid would need to be replaced. Online purification systems can also be used to limit the amount of accumulation of high-boilers in the fluid charge. When operated below the maximum recommended bulk and film temperatures, and not exposed to moisture, air, or process fluid contamination, the HTFs should provide years of fluid service life. The fluid should be sampled regularly, however, for quality in accordance with the recommendations of the HTF supplier. The frequency of sampling will depend upon how close the actual operating bulk and film temperatures are to the maximum recommended values, or if operating upsets or process fluid contamination is thought to have occurred.

B.2.3 Use of Process Fluids as Heat Transfer Fluids

On occasion a process stream can be used as a heat transfer fluid. This is sometimes done to avoid using a commercial heat transfer fluid.

B.2.4 Molten Salts

Various molten salts are available as thermal fluids to suit the specified duty. Their temperatures are raised to the required levels in the thermal fluid heater. The temperature range selected is an important criterion when designing a thermal fluid system.

B.2.5 Molten Salt Heat Recovery Systems

B.2.5.1 The HTF heater is a critical component of the system which can be fuel fired or electrically heated.

B.2.5.2 At temperatures up to 600 °C (1100 °F), molten inorganic salts are suitable thermal fluids for supplying heat to various heat recovery systems. A typical system is shown in Figure B.1. A eutectic mixture of salts with a melting point of 142 °C (288 °F) is often used. The salt remains in the liquid phase under the operating conditions.

B.2.5.3 Salt allows media temperatures of over 500 °C (900 °F) to be achieved without the need for elevated pressures to prevent evaporation/vaporization.

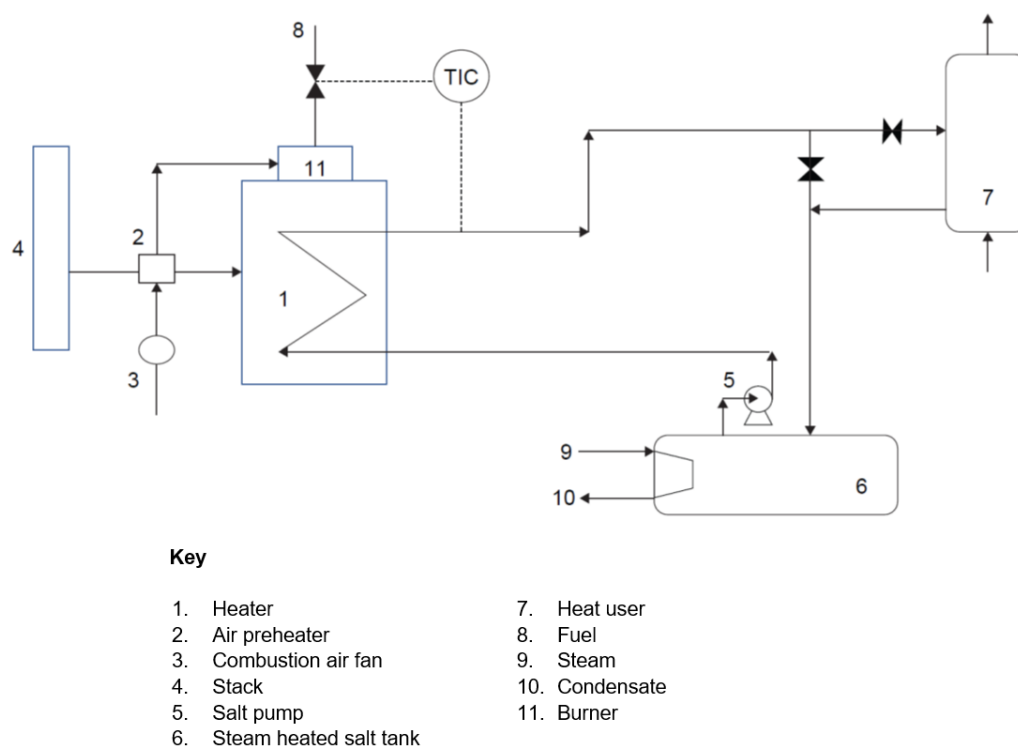
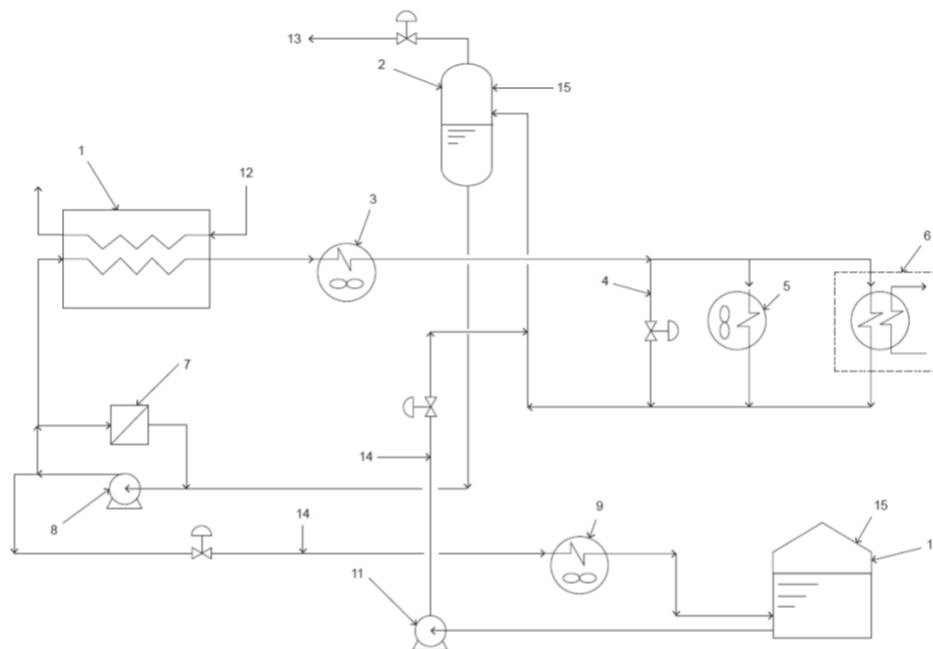


Figure B.1—Typical Molten Salt System

B.3 Heat Transfer Fluid System Components

B.3.1 General

Figure B.2 shows a sketch of a typical HTF system with a waste heat recovery unit. A properly designed HTF system will normally consist of the following components: HTF heater, expansion tank, circulation pumps and piping, strainers and filters, and the process heat exchangers (heat consumers). Depending upon the range of process heating demands and the heating source used, trim heaters, trim coolers, or dump coolers may be required. Storage tanks with makeup pumps, piping, and pump-out coolers may be provided when an inventory of HTF is to be provided on site. The following are guidance for these components.



Key

- | | |
|-----------------------------|----------------------------|
| 1. Waste heat recovery unit | 9. Pump-out cooler |
| 2. Expansion vessel | 10. Storage tank |
| 3. Trim cooler | 11. Make-up pump |
| 4. Full bypass line | 12. Heater or waste heat |
| 5. Dump/trim cooler | 13. To flare |
| 6. Heat consumers | 14. Normally no flow (NNF) |
| 7. Side stream filter | 15. Nitrogen |
| 8. Circulation pump | |

Figure B.2—Typical Heat Transfer Fluid System with Waste Heat Recovery Unit

B.3.2 Heat Transfer Fluid Heater

B.3.2.1 The HTF heater is a critical component of the system. Fuel fired or electrically heated furnaces are commonly employed to provide heat input to the system, but systems using waste heat from gas turbine exhaust or other high-temperature process waste heat streams can also be used and provides for an economic way to distribute and use this otherwise waste heat throughout the process unit. The design of the HTF heater is critical, as this is the location of the maximum fluid film temperature as well as the maximum fluid bulk temperature. The HTF velocity over the heat transfer surface should be maximized as this will result in lower skin temperatures, and dead flow zones which result in high residence times should be avoided. For this reason, liquid tube type heaters, with the HTF contained within coils or tubes, are often preferred. The effect of nonuniform heating, as may occur for example in fired heaters, must be considered when determining the maximum local fluid film temperature.

B.3.2.2 When a fired or electric heater is used to provide heat input to the HTF, the normal turn-down operability of these heater types allows for the heat input to the system to be matched to process heating demands which may be variable. A bypass line parallel to the consumers is provided to control the flow and supply pressure in the system due to consumer trips or demand changes and allows for the minimum flow of HTF through the heater to prevent exceeding the maximum recommended film temperatures. For widely variable systems, an additional bypass line with a trim cooler can be provided for increased operational flexibility. Heaters should be configured with both a high HTF temperature cut-off as well as a HTF low-flow cut-off.

B.3.2.3 When waste heat is recovered for use in the HTF system, from a gas turbine exhaust stream for example, it may not be possible to control the HTF system heat input to match the demand needs of the process. These systems may require supplemental heating devices or equipment such as auxiliary firing duct heaters or trim heaters to provide the necessary heat input, either for the design condition or when the gas turbine is running at lower load or is unavailable. Conversely, an additional trim cooler may be required to dissipate the excess heat when low process heating demand exists at times when the gas turbine output cannot be reduced.

B.3.3 Expansion Tank

B.3.3.1 The HTF system expansion tank provides sufficient surge volume for fluid expansion from its cold start-up condition to its operating temperature condition, which can result in an increase of fluid volume of 25 % or more depending on the specific fluid and operating conditions. The design inventory may also consider the volume of certain system consumers, to allow these to be taken out of service for maintenance while the remainder of the system remains in operation without having to partially drain the system. The tank also serves as the main vent location for the system from which the low boilers can be removed. The expansion tank is typically installed at the highest point in the system and is connected to the suction side of the circulation pumps, for which it provides net positive suction head. Level controls should be provided on the expansion tank. Low level control should provide for protection from the loss of pump suction or pump stoppage. Low level control should also cut off heater input in the event of a loss of fluid volume from the system. High level controls should be provided to allow for the vapor space to be maintained to prevent over-filling, and to indicate an increase in system volume due to a contamination of the HTF from process fluid in-leakage.

B.3.3.2 Due to potential HTF contamination and degradation resulting from oxidation or excessive moisture, the expansion tank should not be left open to the atmosphere. An inert gas (e.g. nitrogen) blanket should be maintained over the vapor space in the expansion tank to minimize fluid oxidation, although cold fluid seal traps can also be used where an inert gas blanket is not practical to provide. The pressure in the expansion tank is typically maintained at a minimum of 100 kPa(g) (15 psig) above the vapor pressure of the HTF.

B.3.4 Circulation Pumps

The HTF circulation pumps must have sufficient capacity and pressure head to serve the needs of the system and must consider the wide range of operating temperatures and viscosities that will be encountered. For large systems, centrifugal API pumps with a stand-by spare are commonly used. Because of the high-temperature service, fluid cooled bearings and seals are recommended, and mechanical seals are commonly employed. The spare pump is normally maintained in a hot stand-by condition due to the high operating temperature of the system. Seal-less pumps, e.g. magnetically-driven and canned motor pumps), also can be used. Proper control system design requires that heat input to the heater be stopped in case of pump failure.

B.3.5 Piping

B.3.5.1 Since the degradation of the HTF increases exponentially with operating temperature when near the maximum allowable bulk temperature, the HTF supply header piping to the consumers should be as short as possible. However, piping design in HTF systems requires attention to the piping flexibility that is necessary to provide for adequate thermal expansion and contraction due to the temperature changes that the system will undergo. The operating temperature of the system is normally above the heat transfer fluid's flash and fire points. Leaking HTF can represent a significant fire hazard when the piping insulation becomes fluid saturated at the high operating temperatures and the fluid undergoes oxidation due to porous insulating materials. For this reason, the use of close-celled high-temperature insulation systems (e.g. cellular glass) that resist fluid saturation are often used. The number of flanged and other mechanical joints should be minimized to prevent leakage, and threaded fittings should be avoided. Valves and stem seals should be chosen specifically for the high operating temperature and the desire to minimize fluid leakage. High temperature packing may be used, but metallic bellows stem seals are often specified for leak minimization. Suitable vents and drains should be

provided in the system to allow for the system to be properly dried prior to commissioning. Closed drain systems for the HTF are normally provided.

B.3.5.2 Strainer baskets should be installed in the pump suction for debris removal during start-up and can be removed for normal operation. Some systems, however, also include side-stream filters for the continual filtration of the system of particulates in the 10- to 20-micron size range as this will prolong the life of the system components and will reduce fouling in the heater and consumers.

B.3.6 Storage Tank

When it is desirable to provide for an on-site inventory of fresh HTF, a storage tank may be provided. The system would include a tank, makeup pump, and a pump-out cooler to cool the heat transfer fluid prior to drainage to the storage tank. The pump-out cooler can be omitted if there is a suitably sized trim cooler included in the HTF system that may be used. The storage tank should be maintained under an inert atmosphere (e.g. nitrogen blanket) to prevent oxidation of the fluid and moisture ingress. The minimum fluid level in the storage tank should be adequate to provide the necessary net positive suction head for the makeup pump. The storage tank may require internal or external heating coils, if required to maintain the HTF inventory above its pumpability temperature for sites with low ambient temperatures.

B.3.7 Heat Exchangers

B.3.7.1 Conventional shell and tube and hairpin type heat exchangers can be used in hot oil and other types of heat recovery systems. Refer to API Standard 660 and API Standard 663 for further details on these types of equipment. Other types of heat exchangers can also be used in these types of systems.

B.3.7.2 The process heat exchangers (consumers) should be designed for efficient heat transfer. Exchangers in HTF service are often subject to thermal shock and rapid temperature changes at start-up. In addition, there may be large temperature gradients between the HTF and the process fluid that may occur during both start-up and normal operation. The mechanical details and selection should be chosen with these conditions in mind to minimize the potential for fluid leakage, either external or inter-stream.

B.3.7.3 When process fluid temperature control is necessary, the HTF flow to each heat exchanger is normally regulated to meet the heat input demand of the process fluid while the supply temperature of the HTF system remains fixed through the control of the HTF heater. Where there may be several consumers requiring heat input at different temperature levels, a zoned temperature system can be provided to serve these exchangers. Each temperature zone would include its own recirculation pump upstream of the exchangers and a bypass line from the outlet of the consumers back the recirculation pump suction. This allows for the blending of the cold HTF from the exit of the consumers with fresh hot HTF to provide temperature control and a lower HTF supply temperature to this zone than that provided for the main system.

Annex C

(informative)

Hot Water/Glycol Systems

C.1 General

Hot water utility systems are similar in design and operation to hot oil systems, with a few notable differences. For instance, hot water systems are normally designed to operate at more moderate operating temperatures than hot oil systems. They are often used to provide heat for general utility services as opposed to process heating demands. They are also used where cold utility water temperatures cannot be tolerated by the process fluid, or at temperatures above which the utility water should be exposed, often called tempered water in these services. In colder systems, glycol is added to the water to lower the freezing point of the mixture.

C.2 Hot Water Systems

C.2.1 Hot water systems are typically closed loop recirculating units that use demineralized water, often treated with anti-corrosion chemicals. When used in locations with low ambient temperatures, the addition of anti-freezing chemicals (e.g. ethylene glycol) may also be considered. The water must be of sufficient quality to allow it to be used at the elevated system bulk and skin temperatures while avoiding significant fouling. Water sampling facilities, with sample coolers, should be provided to allow regular water quality sampling and to allow for the detection of hydrocarbons or other process fluids that may ingress into the system through leaks in the heat exchangers.

C.2.2 Although hot water systems are not subject to the time and temperature dependent decomposition that is prevalent in hot oil systems, the temperature and operating pressure in the system must be controlled nevertheless to prevent unintended vaporization or 'steaming' of the water within the heater which can lead to the deposition and concentration of any impurities in the system or in water hammer issues. To safeguard the system from the risk of steaming, the operating pressure of the system should normally be maintained such that the maximum hot water skin (surface) temperature at all operating conditions is a minimum of 30 °C (50 °F) below the saturation temperature at that pressure. When corrosion treatment chemicals are added to the system, any maximum temperature limits prescribed by the treatment system providers should also be adhered to.

C.3 Hot Water System Components

C.3.1 General

The components of a hot water system are similar to that of hot oil systems. Hot water systems normally use the facility's existing demineralized water system for makeup, and do not require the on-site storage tanks, makeup pumps and run-down coolers that are common for hot oil systems. When no demineralized water system is present, the initial and future system fills may be provided by trucks from a contracted supplier. In addition, a hot water system does not require a purification system as a hot oil system might, although a chemical dosing system may be required based on the water quality and selected system metallurgy for corrosion control. Other differences in components of hot water and hot oil systems are noted below.

C.3.2 Heater

The system heater provided for hot water systems is usually either an electric heater or a waste heat recovery coil from, for example, a gas turbine system. Direct fired heaters are normally not provided due to the more moderate operating temperatures of the water system. In waste heat recovery units, the hot water coils can be located

downstream of other coils, improving the overall efficiency of the system, although auxiliary heating coils in the waste heat recovery unit (WHRU) exhaust duct may be required to meet the hot water system demand during operation of the turbine at reduced loads. High water temperature and low water flow instrument protection is normally provided to safeguard the system against steaming or water hammer.

C.3.3 Expansion Tank

The design of the expansion tank for a hot water system is similar to that of a hot oil system. Nitrogen is normally used for pressurization of the hot water system with high-pressure nitrogen supplied to the expansion vessel. Avoid dissolved oxygen in the system which can cause corrosion over time. A secure and reliable nitrogen supply system should be provided, as loss of pressure in the expansion tank will cause flashing of hot water in the circuit leading to disruption of the plant operation and potential risk of water hammer and consequential loss of containment due to damage to the system. This may require the use of redundant nitrogen compressors or the use of high-pressure nitrogen cylinders. In addition, the expansion tank design should reduce the risk of water carry over from the expansion vessel into the flare system. One scenario that should be considered is a tube rupture inside heat transfer equipment operating at process side pressures above that of the hot water circuit. The process fluid leaks into the hot water side, and then the sudden displacement of fluid from the hot water circuit into the expansion tank can result in water carry over to the flare system.

C.3.4 Trim Cooler

For hot water systems with a WHRU in the exhaust of a gas turbine, a trim cooler should be provided to reject the maximum excess heat possible in the system under all operating conditions including the heat consumer(s) trip scenarios. To eliminate the risk of steaming in the water heating coils due to loss of heat demand in the process and subsequent rise in hot water return temperature, an additional dump cooler is typically used to reject excess heat in the hot water return circuit. The dump cooler is typically sized based on the maximum duty to be dissipated when the hot water is cooled down to the required WHRU inlet temperature from the maximum supply temperature. Then the trim cooler duty should be based on the balance excess heat duty that is required to be dissipated from the system. In the designs with several heat consumers, the trim cooler alone may be sized for the maximum duty absorbed by the coil without a dump cooler when the temperature rise of the hot water is not significant on loss of heat demand from the largest consumer.

C.3.5 Piping System

The hot water piping system design may need to consider measures to minimize the possibility of flow accelerated corrosion (FAC) which is a common phenomenon in demineralized water systems. This typically includes limiting velocities to less than 2.4 m/s (8 ft/s). Higher values are sometimes used when using carbon steel metallurgy, minimizing turbulent areas in the piping system by component design and elimination of FAC as far as practical. The use of higher alloy steels with low levels of chromium ($\geq 1\%$) in the FAC prone areas may also be considered.

C.3.6 Glycol

To handle systems with temperatures where water by itself could freeze, glycol is added to the water to reduce the freezing point. Ethylene glycol and propylene glycol are commonly used. The freezing point is reduced per Table C.1 and Table C.2.

NOTE 1 Combining propylene and ethylene glycol into a single mixture is not recommended.

NOTE 2 Chemical treatment of the system may be required.

NOTE 3 Due to slush creation a glycol and water solution should not be used close to freezing points [i.e. maintain a margin of at least 5 °C to 10 °C (10 °F to 20 °F)].